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ABSTRACT

Diagnostic Cognitive Assessment (DCA) is an alternative dynamic assessment. It aims at measuring cognitive processes for effective learning support and coaching. DCA is embedded in a digital coaching system (DCS) as an executive director. It contains three sub-models: Expert Knowledge Model, Inference Model, and Student Model. While the Expert Knowledge Model emulates human tutoring by modeling the expert tutor's knowledge, probabilistic inferences of knowledge acquisitions are derived from the Inference Models that are driven by Psychometrics and Bayesian Networks. By observing the students' performances, the Inference Models examine and interpret how learners learn as they trace, track, and record learning activities. The Student Model delivers customized diagnostic analysis to learners, guidance to DCS's Scaffolding function to map the learner's knowledge structure and schema, immediate dynamic diagnosis to Real Time Evaluation of DCS, and aids to collaborative learning in the E-Learning Community. (Contains 27 references.) (Author)

Diagnostic Cognitive Assessment and E-learning

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Abstract: Diagnostic Cognitive Assessment (DCA) is an alternative dynamic assessment. It aims at measuring cognitive processes for effective learning support & coaching. DCA is embedded in a digital coaching system (DCS) as an executive director. It contains three sub-models: Expert Knowledge Model, Inference Models, & Student Model. While Expert Knowledge Model emulates human tutoring by modeling expert tutor's knowledge, probabilistic inferences of knowledge acquisitions are derived from Inference Models that are driven by Psychometrics and Bayesian Networks. By observing the students' performances, the Inference Models examine & interpret how learners learn as they trace, track, and record learning activities. Student Model delivers customized diagnostic analysis to learners, guidance to DCS's Scaffolding function to map learner's knowledge structure and schema, immediate dynamic diagnosis to Real Time Evaluation of DCS, and aids to collaborative learning in the E-Learning Community.

Introduction

E-learning is expected to provide environments that promote metacognition: thinking about thinking via electronic conferencing, and collaborative learning in the virtual learning communities. It can entail the transformation of learning: from a product to a process. While knowledge is being constructed by individual learners, and co-constructed and shared with peers and experts globally via the Information Communication Technology, it is represented and re-engineered through innovations and creativity with high end technology such as simulations, and electronic coaching system. This continuum involves cognitive processes, learning, and knowledge and skill development. This phenomenon coincides with the contemporary theories of cognition and social constructivism that "emphasize the way knowledge, organized, and processed in the mind" (Pellegrino et. al., 2001, p.3) in a social context in which knowledge is actively manipulated for problem solving.

However, the rise of e-learning also intensifies what Frederiksen (2002) has described as the incompatibility between the conventional measurement models that underlie current practice in educational assessment and modern theories of the cognitive and social processes that are involved in learning and skilled performance, particularly in the dynamic holistic e-learning context. Why? Shepard (2000) stated that the current practice assesses learning achievements as products. It focuses on a) component skills rather than proficiency in solving practical problem in authentic settings, and b) discrete bits of knowledge rather than critical thinking and knowledge application. The assessment goal mostly focuses on giving grades or to satisfy accountability demands. Does this type of assessment support and enhance learning? Shepard (2000) advocated that assessment is for learning, and pointed out that in-depth and ongoing assessment genuinely increases learning. Frederiksen and Donin (1999) declared that there has been a growing recognition of the needs for an alternative assessment - more authentic cognitive assessment. This is an assessment that measures performance and achievement, and assists learning and instruction.

Cognitive assessment has been recognized as one of the great challenges for the field of measurement and evaluation (Snow and Lohman, 1989 & 1993; Embretson, 1990; Samejima, 1995; Pellegrino, James W., Chudovsky, Naomi, and Glaser, Rober, 2001). I attempt to formulate an assessment framework addressing the assessment of students' cognitive processes and knowledge structures. In this paper, I will describe a cognitive assessment framework that integrates measurement into both learning processes and performances as a vehicle to enhance learning and instruction to the fullest potential. It is named as Diagnostic Cognitive Assessment (DCA). It will be developed and embedded in a digital coaching system (DCS).

Diagnostic Cognitive Assessment (DCA)

Taking the advantage of technological as well as substantive theoretical advances, assessments can improve education. On the one hand, psychometric theory and test design principles are reviewed and expanded, new cognitive assessment theories and models emerge to deal with different measurement issues (Samejima, 1995; Embretson, 1990; Sijsma, & Verweij 1999; Lesgold et. al. 1989; Junker & Sijsma; 2001). On the other hand, technological advancement enables rapid and potent measurement potentially. The rise of e-learning as a buzzword for innovative approaches to education implies that I cannot reiterate, or summarize adequately the extensive reports on interesting thesis, promises, cautions, and criticisms that have been published on e-learning. Among all these reports, assessments in e-learning are important but its focus is not on assessing cognitive abilities and cognitive achievements of the students but rather on cost effectiveness. The current assessments in e-learning mostly still remain within the conventional assessment models.

Furthermore, although a learner-center approach, e.g. Veen, Collis, Santema & Genang, (2000), and constructivism, e.g. Hoddinott. (2000), are often the basis for centers investigations, good examples of the integration of diagnostic and cognitive assessments into instruction, learning and testing for e-learning was not found during my literature research. Upon my observation, the current focal point of assessments in e-learning is on how to manipulate technology rather than the assessment itself.

Technology provides e-learning with a powerful tool for a new possibility. Snow & Lohman (1993) stated that: "The possibility now exists to bring new concepts and measures of aptitude, learning, development, and achievement, together with instructional innovations, to create truly diagnostic and adaptive systems." (p.1). The main challenge is how to use all these available technological advances for the creation of such a diagnostic adaptive system. DCA is to be a response to this remark for a truly diagnostic and adaptive system of assessment.

DCA is generated from cognitive and diagnostic assessments. It focuses on inferences about learning competence. It aims at measuring learners' cognitive processes, learning, knowledge and skill development for diagnostic purposes. Using a medical analogy, a diagnostic assessment is to detect and define an existing learning problem before providing a cure for the problem (Lesgold et. al., 1989).

Diagnostic assessment emerges from theories of instruction, aptitude and cognition (Embretson, 1990; Glaser, 1985). It has been considered as a redesign of testing for the 21st Century. Embretson (1990) associates diagnostic assessments with dynamic testing that is defined as a measurement of learning processes by examining the consequences of instruction. Marshall (1990) and Lesgold et al (1989) point out that this assessment involves identifying causes or sources of resulting phenomena, decision making about intervention, and specifying a treatment to a problem. Instruction is changed to be adaptive and responsive to students' personal styles and conceptions (Snow and Lohman, 1993) in specified learning situations for a domain.

DCA extends the arena of diagnostic assessments from improving instruction and testing to the development of an effective learning environment. Students learn as they are solving problems for the tests (Shepard, 2000) in which they are challenged to perform. DCA re-conceptualizes assessments as an adaptive assessment-learning system. It is conceived as a coaching, learning and testing tool that is responsive to the student's individual characterizations and to the situation. It not only includes the mechanism for a) deciding characteristics of learning by examining the students' performance, b) careful investigation of the facts of knowledge acquisitions and skill mastery levels, c) formulating diagnostic interventions based on inferences of evidences, but also an agent for learning - students are coached to learn by solving the given problems that are in the form of tasks as test items of an assessment. Computerized assessment offers DCA can integrate diagnostic cognitive assessments into e-learning. It supports, directs instructional interventions and learner-centered learning, and operates the digital coaching system (a system that assist/coach learning in an electronic environment) with three models: Expert Knowledge Model, Inference Model and Student Model. In synchrony, these models interconnected with and are interdependent on each other.

1) Expert Knowledge Model

The expert Knowledge Model is built as presentations to a) explain the characterizations of how the mind of an expert works, and b) predict about what are the best strategies and knowledge an expert uses to solve problems and how these strategies and knowledge are applied within a defined circumstance.

The model plays two roles of experts in subject matter and pedagogy. As a subject matter expert, it provides DCA and the digital coaching system with the content knowledge of a domain. It also organizes and validates concepts and principles of a domain. As a pedagogical expert, the model supports the coaching activities with "pedagogical reasoning and action" (Donald, 2000, p.37) - the capacity to transform content

knowledge into forms that are pedagogically powerful and yet adaptive to students of various abilities and background (Donald, 2000). The model uses the expert knowledge and produces its knowledge representations for testing, instruction, and learning. These representations can be elucidated with three kinds of learning schemata described by Donald (1987): cognitive structure, curriculum structure, and content structure. Based on the learning schemata introduced by Donald (1987), a graphical representation of the learning schemata of the Expert Knowledge Model explains the constitution of its knowledge representations (see Figure 1 below).

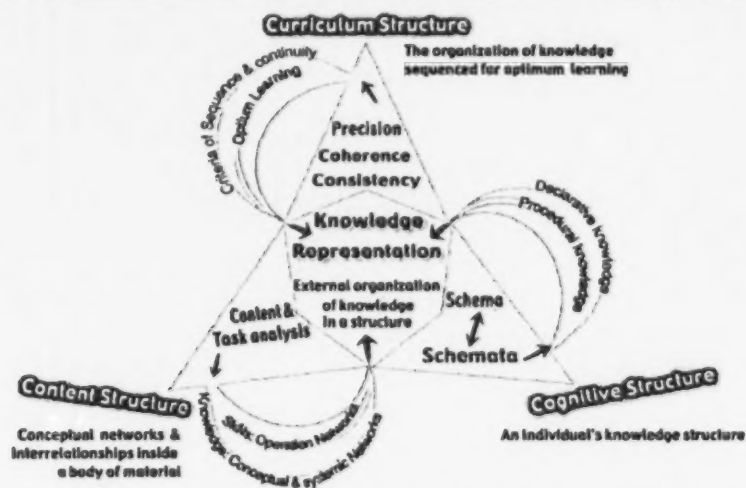


Figure 1: Learning Schemata of the Expert Knowledge Model

As figure 1 indicates the curriculum, cognitive and content structures are interrelated with and interdependent on each other for an effective knowledge representation made for the optimization of coaching and learning. At the base of the triangle, as a support to Curriculum Structure, an expert schema, i.e. data structure for representing generic concepts (Donald, 1987), directs the operations of content and task analysis. This analysis decomposes the domain knowledge into procedural and declarative knowledge for formulating tasks as learning activities and test items. With the inputs from content and cognitive structures, a curriculum structure represents an optimization of learning by determining what steps to should be taken to a) optimize learning, b) sequence the content knowledge, pedagogical and learning activities in continuity, and c) limit or delimit the knowledge domain. While depicting how learning is measured, in order to be accountable, it ensures its learning schemata is acceptable to other experts in the domain and meet criteria of Precision (the accuracy of the representation), Coherence (the components of the representation are closely related internally), and Consistency (the components of the representation are related to existing knowledge in an overall cognitive structure) (Donald, 1987).

Expert models have been used in Computer Based Learning in various terminology in different forms with different purposes. Upon my observation, although this kind of model is not new, a model that integrates assessment into instruction and learning have not yet been established, e.g. BioWorld (Lajoie, 2001)

In forming the basis for developing diagnostic assessments, Frederiksen and Donin (1999) point out that conceptual knowledge and problem-solving procedures in a domain essentially derive from an expert model. A computer coach can be engineered to combine dynamic assessment of learning with diagnostic assessment of student's problem-solving processes (Frederiksen and Donin 1999). The goal for the future research will be to examine how expert models can be constructed to support diagnostic cognitive assessments.

2) Inference Models

"In any inference task our evidence is always incomplete, rarely conclusive, and often imprecise or vague; it comes from sources having any gradation of credibility. As a result conclusions reached from evidence having these attributes can only be probabilistic in nature." (Schum, 1994, p.xiii; cited in Mislevy, 1996)

The inference models aim at making inferences about students and how knowledge and skills are acquired for the provision of guidance to student learning and adaptive instruction. Its task involves capturing,

storing, and communicating the multitude of evidence resulted from inferences to the digital coaching system (DCS) for actions, and formulating the Student Model. Those tasks are harnessed by psychometrics and Bayesian Networks that take a statistical probabilistic approach to reasoning from evidence. How do they conduct the tasks? Observing the processes of testing and the test results, based on derived evidence, inferences are made from: a) a statistical psychometric model that characterizes the patterns in the data for students at varying levels of competence, b) Bayesian Networks that produce causal networks by tracing, tracking and recording student performances and strategies of problem solving during the learning process. The conclusions drawn from these inferences are probabilistic assumptions about the underlying cognitive constructs of the students' performances (Pellegrino et. al., 2001). Figure 2: Statistical Inferences shows how probabilistic prediction is concluded from inferences derived from evidences that are generated from data.

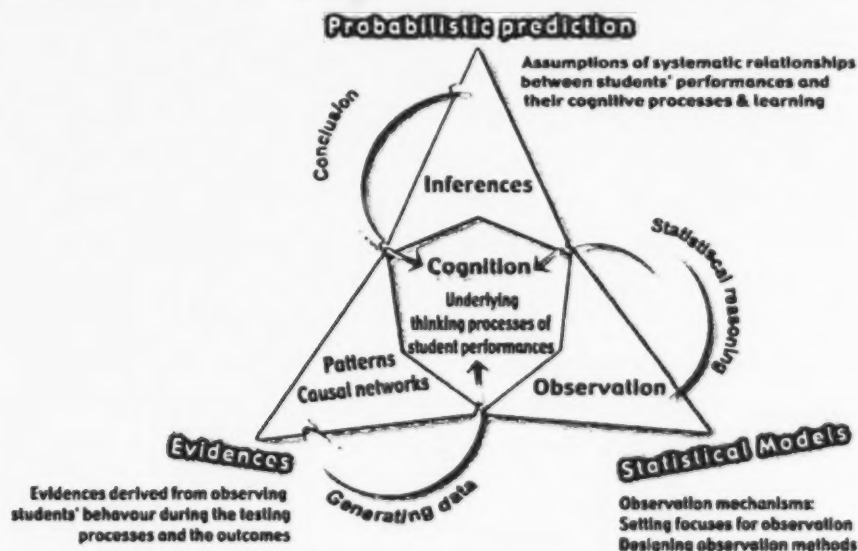


Figure 2: Statistical Inferences

During the process of diagnosis, on the one hand, psychometrics provides observers with task-based observations for making probabilistic inferences about the mastery level of the domain knowledge. After the identifying specific features of problems or difficulties learners have during the learning process, psychometrics examines the consequences of coaching before defining intervention characteristics. On the other hand, Bayesian Network traces, tracks, and records all the learning performances. From these accumulated processed experiences, Bayesian Networks formulates "causal structures" (Tian & Pearl, 2001) to a) interpret the effects in a defined situation and search for their causes, b) decide for intervening actions in real time, c) adapt to changes and learn from experience (Jensen, 2001) for updating diagnosis and the provision of coaching and learning guidance d) provide assessors or administrators a reliable graphical representation of instructional and learning processes that will allow them to make informed decisions (Martin, & VanLehn, 1995).

The combined use of psychometrics and Bayesian Networks provides DCA with advances in probability-based reasoning advocated by psychometricians, such as Junker & Sijsma (2001) and Samejima (1995) and graphical statistical modeling recommended by Pearl (2000). Mislevy, (2000) pinpoints that these advances extend the principles that underlie familiar test theory to more varied and complex inferences from more complex data.

Using psychometrics in conjunction with Bayesian inference networks diagnostic testing is considered as new testing approach advocated by Mislevy (1993), and Frederiksen, Missley & Bejar (1993). Missley (2000) states that: "Opportunities borne of new technologies, desires borne of new understandings of learning—a new generation of assessment beckons." (<http://www.ncme.org/about/awards/mislevy.html>). This vision is shared by others. For examples, VanLehn, Niu, Siler and Gertner (1995 a) take this approach in the research on determining a fine-grained size of knowledge representation in diagnostic testing. Junk and Sijsma (2001) employ similar approach in the research of usability and interpretability issues for single-strategy

cognitive assessment models. Mislevy, Steinberg, & Almond (2000) also incorporated this conjunctive approach into their Evidence-Centered Assessment Design. This Inference Model of DCA can emerge as a new generation of assessment if it is supported by future research.

3) Student Model

Understanding students' knowledge acquisition and cognitive processes is essential for diagnosis. Explicit representations of these attributes are required at a level of cognitive complexity that facilitates successful performance and understanding (Kieras, 1988). However, these attributes are unobservable variables that are subjected to inferences derived from evidence (Pellegrino, Naomi, & Rober, 2001). Three kinds of reasoning are employed to construct these representations with advanced computer technologies, e.g. interactive interface, and inference tools, i.e. Bayesian Networks and Psychometrics. They are a) deductive reasoning that flows from generals to particulars, b) inductive reasoning that takes the opposite direction of from effects to possible causes and 3) abductive reasoning that proceeds from observations to new hypotheses, new variables, or new relationships among variables (Mislevy & Gitomer, 1996).

The constructed representations formulate the student model that is composed of dynamic profiles about students characterizations. The model is built as representations that a) explain the characterizations of the learners' cognitive processes, i.e. the schema b) infer, and identify the mastery level, errors, misconceptions, and knowledge gaps, c) predict about what is the best to coach the learners, d) confirm such predictions. Figure 3: Student Model depicts how the Student Model is supported, and functions within DCA.

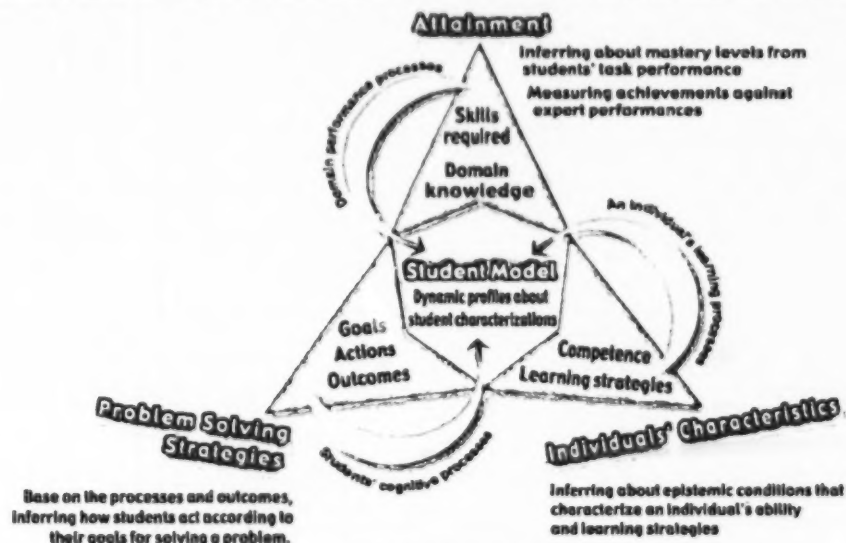


Figure 3: Student Model

The student model is comprised with three components: Attainment, Problem solving strategies, and individual characteristics. Each of them addresses different functions of the model. Attainment approximates beliefs about the level of the students' competence and task performance of a domain and their interrelationships. The comparison between the students' and an expert's problem solving task performance is an indicator for identifying accomplishment, errors or misconceptions, and knowledge gaps. The resulted inferences will form the basis for generating appropriate content materials, sequencing tasks and learning units for coaching and diagnostic testing.

Next, the Problem Solving Strategies deals with particular knowledge states of individuals. It makes inferences about how students use goals to guide their actions for expected outcomes, i.e. solutions for given problems. This epistemic process involves hypothesis making that generates goal establishment, testing hypothesis leads to actions, and outcomes resulted from actions taken. Students' problem solving strategies suggest an explanation of how the students think when they learn. This explanation will pinpoint cognitive information about an individual student. It can serve as inputs to pedagogical reasoning and action.

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Finally, Individuals' Characteristics contains the schema of individual students. Based on inferences, it presents students' epistemic conditions that characterize ability and learning strategies for each individual students. It can provide information to suggest how to customize learning tasks and scaffolding, and testing that are adaptive and responsive to each student's characterizations. The knowledge about an individual's characterizations supports a) collaborative works by matching different students of different competence, b) finding the most competent peer who has good knowledge of a specific topic in a domain for peer support or peer review, c) generating modeling (examples) that map with the needs of a student for coaching d) pedagogical decision making, e.g. when and how to apply fading in which situation during the scaffolding process.

Student model is used in ITS to support flexible individualized learning and instruction, for example, SHERLOCK ITS (Lesgold et al., 1992) and HYDRIVE (Mislevy & Gitomer 1996). However, in e-learning, i.e. web-based learning systems, student model is underdeveloped, most of the so-called e-learning system is nothing more than a network of static hypertext pages. Interactivity in and adaptations to learning are limited (Brusilovsky, 1998).

DCA concerns the essential role of assessment for improving instruction, learning and testing in DCS. DCA is conceptualized as a) a tool to approximate student proficiency through the combination of detailed epistemic analysis of student performances within the Inference model with probability-based inference; b) an environment in which inferences of students' cognitive processes formulate the foundation of accurate prediction on students' proficiency and attainment. This prediction is validated by inferences derived from students performances and the dynamic Student Model; c) a crucial support to pedagogical reasoning and action. It enables DCS to provide coaching that is adaptive and responsive to the students' level of competency, and characterization.

DCA and Digital Coaching System (DCS)

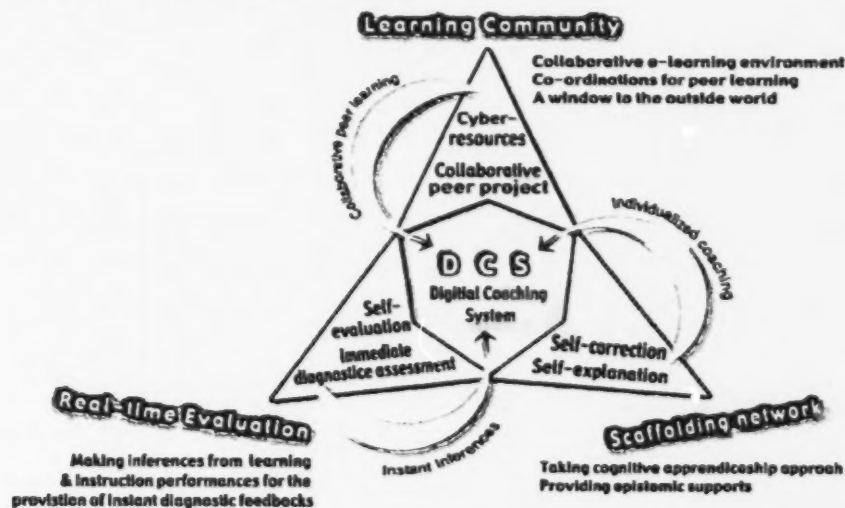


Figure 4: Digital Coaching System

The DCA is embedded in DCS as a monitor of the coaching activities. DCS resembles to an intelligent tutoring system (ITS) but it is not ITS because it is not merely an automated system. DCS is a) learner-centered – learners are in control of their learning, and b) dynamic – DCS has the capability to learn from its coaching experiences and observation of the learners' performances, it customizes coaching based on individual learners' needs and characterization. As Figure 5 illustrates, the system is composed of three interrelated and interdependent mechanisms: Scaffolding Network, Learning Community and real time evaluation.

The Scaffolding Network is devised to mediate individualized coaching that takes cognitive apprenticeship approach. Based on an understanding of a student's characterization and competence, the Scaffolding Network models the domain knowledge as examples, and generates prompts and hints to stimulate and scaffold self-explanation and self-correction. The scaffolding processes are traced and recorded by the Bayesian Nets that a) supports the decision making of the Scaffolding Network, b) provides real time diagnostic evaluation of the student

performance and instructional intervention for self-correction of both parties, and c) co-ordinate scaffolding activities in the learning community for collaborative works.

Real-time Evaluation is a computational framework driven by Bayesian Networks with the support of an Internet server. It makes inferences from instruction and learning performances for a) generating diagnostic feedback and achievement assessments, b) updating the Student Model, and c) matching students to form collaborative work group.

Learning community is a collaborative e-learning environment for peer reviews, group projects, and posting of the students' knowledge representations, such as papers, simulations, and presentations. It is also a window for outreaching on-line resources, such as interactions with international experts, on-line conferences, and virtual libraries and journals.

These three mechanisms interact with each other and work together simultaneously. Their functions and interactions are described below in Table 1.

Pillars	Scaffolding network	Learning Community	Real Time Evaluation
Scaffolding Network	Ftns: - Elicitation of knowledge from the learners - Explanation of knowledge and concept - Demonstration of skills - Generating hypothesis for testing	- Setting up reasoning tactics - Defining the problem space - Representation of knowledge - Setting up and testing hypothesis - Consolidating & reinforcing learning - Formulation of comprehension via collaborative learning, e.g. discussions	- Providing immediate advice & guidance - Recording time spent on each task - Recording & tracking learning performances as evidence - Based on evidence inferring causes and predicting the effects of a performance
Learning Community	Ftns: - Provisions of a) learning resources, such as on-line libraries, b) a collaborative learning environment, c) a stage for demonstrating/illustrating knowledge representations, such papers, simulations, and presentation.		- evaluating & inferring learning by studying changes shown in the evidence
Real Time Evaluation	Ftns: - Tracking and recording learning performance, - Providing real time guidance to learners, & diagnostic information to coaching during learning		

Table 1: Functions and Interactions of the Pillars

Ftns:Functions

Conclusion

The DCA framework described here offers an e-learning environment for coaching, learning and assessment simultaneously. As an evaluation, the framework shall be able provide objective and cognitively valid measurement of learning performance. As a diagnostic assessment, it should support instruction (coaching) and learning with reliable and valid inferences and predictions in real time. Moreover, the real time evaluation can be used to provide the coaching system and learners with diagnostic information about learners' comprehension and problem solving, including errors and misconceptions. To sum up, DCA does not only integrate assessment into instruction for the collaborative learning and problem-based learning, it also provides an innovative framework of cognitive assessment with the advanced technologies effectively for the sake of learning, not merely for using technologies. If future research can show this model can be implemented, then, it may offer one solution to the problem of assessment that is valid and reliable in measuring learning performances and learning processes for the enhancement of both instruction and learning to their best potential.

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